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Recognition of the fault regimes for the remote electrical objects

Nagay I.V., Nagay V.I., Kireev P.S.*

Platov South-Russian State Polytechnic University (NPI), 132, St. Prosvescheniya, Rostov region, Novocherkassk, 346428, Russian Federation

Abstract

This issue is urgent. Russian 6 to 110 kV electric networks are among the most widespread and extended and supply power to both industrial and municipal customers. It is a frequent case that networks of the voltage classes are based on the radial principle that simplifies the relay protection and automation (RPA), but at the same time the use of a simple technical solutions is problematic in terms of technical and informational performance as compared to solutions of higher voltage class networks. This is particularly evident in the backup protection design.
Herein are proposed solutions. Expanding the knowledge base of relay protection and the use of adaptive principles in design thereof can solve the abovementioned problems. The paper discusses the issues of improving the sensitivity of relay protection with the relative selectivity that ensures recognition of fault for the electrical "remote" objects. This approach is discussed as an example of relaying electrical networks, which include overhead lines and transformers. Increase in the number of monitored parameters in addition to the information signs in some cases can prevent damage and eliminate the "dead" zone with the fault recognizability effect.

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Keywords:"Relay protection; short circuit; selectivity; high-speed activity; transient resistance; electrical arcs."

1. Main text

Assessment of the informational signs, that characterize the reporting regime, such as the electrical distribution network shown in Fig. 1, is needed to solve the problem of recognition of phase fault with transient resistance of the electric arc (EA). Remote backup protection (RBP) are connects to current transformers TA1 and voltage

* Corresponding author. Tel.:+7-863-525-5291; fax: .:+7-863-525-5291.
E-mail address: nagayiv@mail.ru

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transformers TV1 on the side of power supply substation and provides monitoring of the currents and voltages and their components (symmetric, orthogonal, emergency, etc.). Local backup protection (LBP) is installed on the branch or intermediate substation and provides monitoring of the currents, voltages from the higher and lower voltage sides, neutral current, as well as, for example, the luminous flux inside the compartments complete switchgear low voltage side. This allows to expand the information base of local backup protection compared with RBP.

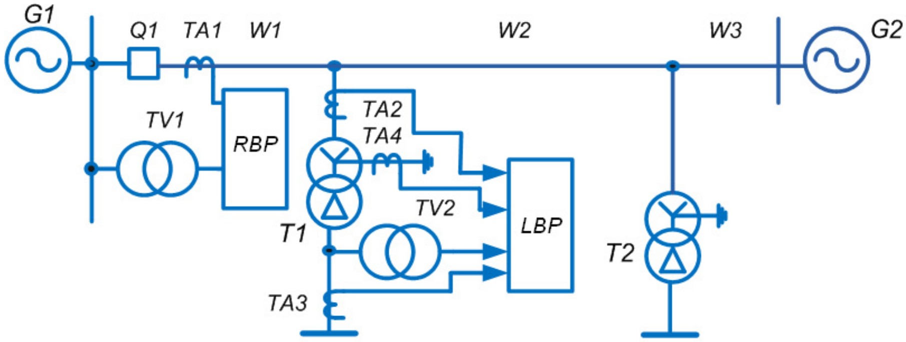

Fig. 1. Explanatory scheme of remote and local backup protection in the electrical network with branch substation.

It is necessary to specify ranges of parameters of informational signs of this type of fault on the base of the proposed classification for the minimization of the impact of the transient resistance on the functioning of the RBP and LBP: the increase in the active component and the stability of the reactive component of resistance of the short circuit chain, non-stationary EA processes, the presence of higher harmonics and symmetrical components in the current and voltage, the evolving nature of the fault, the presence of the luminous flux from the column of EA.

Transient resistance of electric arc is an active character and its presence leads to a reduction of current modules and current arguments [1-12]. This causes an increase in the total resistance of the short circuit. Modules of the current of the short circuit are reduced to 80% of the current level of the metal short circuit (SC), the value of the argument is reduced to a value $0{,}6\varphi_{MSC} = 55^o \div 60^o$, and transient resistance reaches values $0{,}6Z_T$, when the voltage on the electric arc changing $U_t = U_a = (0 \div 0{,}3)U_{nom}$.

Transient resistance of EA that representing the non-linear resistance for phase short circuit, causes the appearance of the higher harmonic components (HHC) in voltages and currents. Currently, the use of HHC is not widely used to recognize the arc fault, and it led to these studies.

Many factors affects the EA process [1,3-9]: airflow, electrodynamic effects, changes in the electrical conductivity of the medium, temperature changes, etc. There are as an extension of the arc column and its shortening by grafting individual sections with subsequent inflating by the air streams when electric arc is burning.

Non-stationary processes arc appears in one period of industrial frequency and from period to period. The voltage drop on the arc columns of the various phases are not the same, that causes the appearance of asymmetry. It marked hysteretic current-voltage characteristics of an electric arc "phase voltage - phase current". Changes in arc length results in a change of the voltage drop on it $U_a = E_a l_a$. It is reason of change of the short circuit resistance, modules and arguments of the current, as discussed in [13-16], i.e. signal parameters controlled by the RBP and LBP are changing because the process of high-voltage electrical arc is non-stationary, it is a sign of an arc fault.

Process EA may be associated with the movement of the arc column under the influence of air flow, electrodynamic forces on electrical parts and with changing of the type of fault. Single-phase ground fault can develop into a double-circuit to ground, and the next stage due to the small distances between under-voltage parts on the side of low voltage of 6-10 kV protected transformer develop in a phase to phase fault.

Two-phase short circuit is accompanied by the appearance of symmetrical components of negative sequence, that allows to effectively provide for the recognition of short-circuit for the protected transformer, especially when it designed coils' star - delta "[13]. If it SC switches to a three-phase short-circuit, asymmetry not disappears due to inequality of the lengths of arcs and possible their combustion between the outer and middle phases [13-16]. At the same time negative sequence current reducing and can be about (10 ÷ 15)% of the current of the three-phase short-circuit for the transformer [13-16].

Authors of the article noted, when they had field tests on substations 110/10/6 kV, that zero sequence voltage $3U_0 \leq 500$ appeared when it was phase fault with an electrical arc in electrical cabinet design of 6-10 kV.

Solutions.

Authors offers some ways for recognition of the arc SC [11–20]:

- cooperative monitoring of the current modules and the current arguments, their fault components, resistance (fault component);
- monitoring of the presence of negative sequence current and it values;
- monitoring of the higher harmonic components of the voltage;
- monitoring of the change of the type of the fault (single-phase ground fault, two-phase short-circuit, three-phase short circuit), and non-stationary process of arc column ;
- monitoring of the luminous flux in conjunction with the current, especially in the electrical switchgear.

It should be noted that the proportion of higher harmonics in the current is not more than 5% of the first harmonic component of the current of the short-circuit. Calculation of the fault components of the current and voltage at the installation site protection, including the harmonic components of the signal, is possible, if transient resistance of the arc in the fault on the low voltage side of the transformer of the branch substation presents in the form of a non-linear resistance [3-7].

Authors developed a mathematical model of the electrical network by the software package Mathcad (Fig. 2) to determine the harmonic components in the presence of non-linear transient resistance, that depends on the instantaneous values of voltage and current.

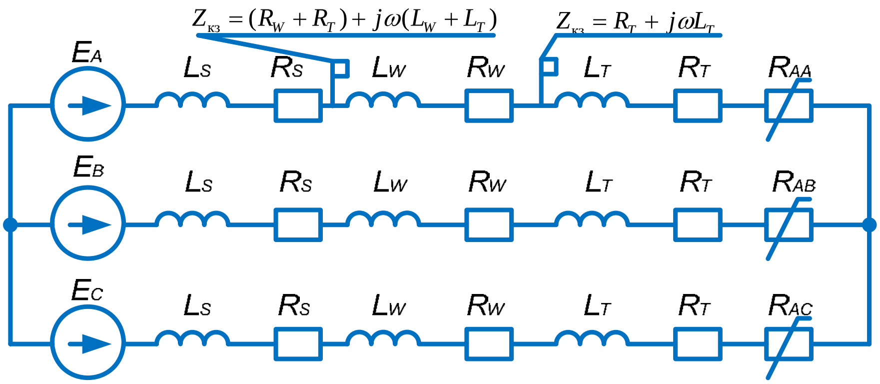

Fig. 2. The equivalent circuit scheme of 110 kV network "power supply - overhead line - transformer with resistance of electric arc".

The current-voltage characteristics (CVC) of the electric arc described by the ascending and descending branches in form of straight lines in the field of the non-self discharge [3-7,14-16].

$$u_{a,a} = i_a U_s / I_s \text{ и } u_{a,d} = i_a U_q / I_q \,, \tag{1}$$

It can be assumed in the area of self discharge that the change in voltage on the electric arc is exponential and is described by the following expressions:

$$u_{a,a} = U_{min} + \left(U_s - U_{min}\right) e^{-3\left(i_a - I_s\right)/(I_{max} - I_s)} \text{ at } i_a \geq 0 \,, \tag{2}$$

$$u_{\mathrm{a,d}} = U_{\min} + \left(U_{\mathrm{q}} - U_{\min}\right) e^{-3\left(i_{\mathrm{a}} - I_{\mathrm{q}}\right) / (I_{\max} - I_{\mathrm{q}})} \text{ at } \mathrm{i_a} \le 0, \tag{3}$$

The simulation results were used to determine the optimal set of information signs of harmonic components and the sensitivity analysis of the measurement signals of different harmonics as the distance of the observer from the fault location to the power source. Values of the relative magnitude of voltage different harmonics (base quantities take the voltage fundamental harmonic of 50 Hz) are shown in Fig. 3. Relay protection device (conditional observer - the figure represented by the symbol) could be in different locations of the equivalent circuit. Removes the observer from the point of fault have been assessed on the basis of the ratio $\mathrm{k} = 1 - \mathrm{Z_{sc}} / \mathrm{Z_{\Sigma eq}}$, where $\underline{\mathrm{Z}}_{\mathrm{sc}} = (\mathrm{R_W} + \mathrm{R_T}) + \mathrm{j}\omega(\mathrm{L_W} + \mathrm{L_T})$ – resistance of the branches that current flows from the observer to the place of fault.

Greatest amplitude signals have the first, third, fifth, sixth and seventh harmonics. Comparison algorithm of the sum of the quantities of harmonic voltage components in fault location with the value of the voltage fundamental can be implement for identifying transient resistance. Comparison of the sum of the quantities of harmonic voltage components in fault location with the magnitude of the voltage fundamental harmonic conducted for the frequency range from 100 Hz to 750 Hz at a distant observer from the source to the point of fault $\mathrm{k} = 0.1 \div 0.995$.

Development of changes in the sum of voltage values of harmonic components in the short circuit site for the frequency range from 100 Hz to 750 Hz at a distant observer from the source to the point of fault $\mathrm{k} = 0.1 \div 0.995$ is showed that the quadratic sum of a small deviation from the actual voltage value of the first harmonic $\mathrm{U_{\Sigma quad*}} = 1.0 \div 1.08$, and the algebraic sum has advantages for detection transient resistance in the short circuit - $\mathrm{U_{\Sigma alg*}} = 1.0 \div 1.71$. Using the algebraic sum of the harmonic components of the voltage in the monitoring location has the advantage compared with the parameter of the quadratic sum, because it varies considerably larger, for example, for values k> 0,9, that corresponds to an approaching of the observer to the fault site exceeds the maximum of the quadratic sum of the voltage harmonics of 1.7.

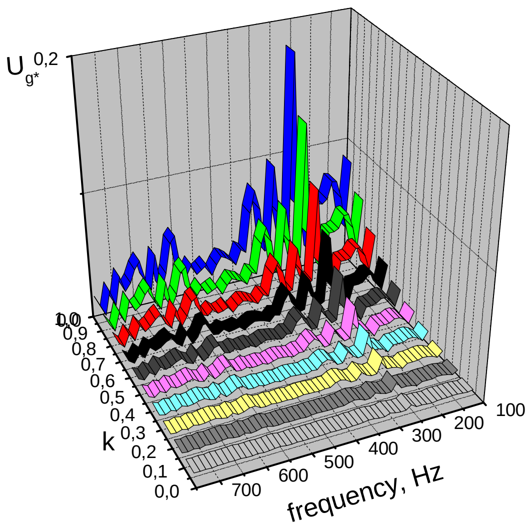

Fig. 3. The harmonic structure of a voltage at the protection installation site at a relative electrical distance from the protection installation to the fault.

Additional information sign of the three-phase asymmetric short circuit is change of the ratio of the frequency structure of the voltage at the point of observation (installation site protection) when type of short-circuit is changing, for example, if one of the three arcs is shunting and burning of two arcs between the middle and edge phase wires after that. For example, there are changing the ratio between the third, fifth and seventh harmonics.

Ratio of the information sign of voltage harmonics are changing $|U_5|/|U_7| = 1{,}27 \div 2{,}6$, $|U_6|/|U_3| = 0{,}61 \div 2{,}31$, $|U_7|/|U_6| = 1{,}47 \div 0{,}77$, $|U_5|/|U_3| = 1{,}15 \div 4{,}66$ when arc resistance R_{AB}/R_{BC} are changing from 0,5 to 2 and R_{BC} is permanent resistance.

Conclusion

It defines the basic information signs of arc short-circuit: increase of the currents active component and their components; the presence of the higher harmonic components in the voltage; non-stationarity of the short circuit processes; the appearance of asymmetry at the three-phase faults with negative sequence current, that magnitude reaching 15% of the current of the metal short-circuit; appearance of the voltage zero sequence on the low voltage side of the protected transformer up to 500 V; the evolving nature of the fault "a single-phase circuit - a two-phase short circuit - three-phase short circuit", "two-phase short circuit - three-phase short circuit"; appearance of the light flux from the arc column, that represents the emitter.

There are founded most informative higher harmonic components of voltage for three-phase symmetrical and asymmetrical short circuit arc. The modules of the second, third, fifth, sixth and seventh harmonics are within the range (7,5÷18)% of the first harmonic component of the fault site.

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Nomenclature

U_t	voltage on the transient resistance
U_a	voltage on the arc
U_{nom}	nominal network voltage
φ_{MSC}	current argument of the metal SC
Z_T	transformer resistance
E_a	electric field strength of the arc column
l_a	length of the arc column
$u_{a,a}$	voltage on the ascending branch
$u_{a,d}$	voltage on the descending branch
U_s	ignition voltage
U_q	voltage with quenching the arc
I_s	ignition current
I_q	current with quenching the arc
U_{min}	minimum value for the arc column
$Z_{\Sigma eq}$	equivalent resistance of the short circuit
R_W	resistance of the overhead line
L_W	inductance of the overhead line
R_T	resistance of the transformer
L_T	inductance of the transformer
R_S	resistance of the system
L_S	inductance of the system
E_A	voltage of the power sources phase A
E_B	voltage of the power sources phase B
E_C	voltage of the power sources phase C

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